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A Compact Dual-Band, 9 Circle Receiving Array — Part 1

Low band receiving arrays constructed of electrically short vertical elements are not a new concept[1] (notes appear at the end of this article). ON4UN's *Low-Band DXing* devotes a considerable portion of an entire chapter to this topic.[2] The best-performing systems provide very high directivity, which is the basis for rejection of unwanted noise and interference, and the ability to steer the pattern in multiple directions. Low band systems of this type typically require considerable real estate, however. Because of this, relatively few amateurs deploy them. I was not among those fortunate enough to have room for a big array on his property.

The array I'll describe offers an alternative for those of us who are space-challenged, but it sacrifices little in receiving performance. It is an array of nine short, vertical elements — I use a height of 15 feet — arranged within a circle of just 140 foot in diameter. It provides eight switchable directions of azimuth coverage on 160 *and* 80 meters, and its receiving directivity factor (RDF)[3] on 160 meters is 12.2 dB at 20° elevation, within about 1 dB of some of the highest performing vertical receiving arrays now in use. The design is *optimized* for 160 meters but, as a bonus, provides very good performance on 80 meters too, without the need for band switching or any kind of reconfiguration.

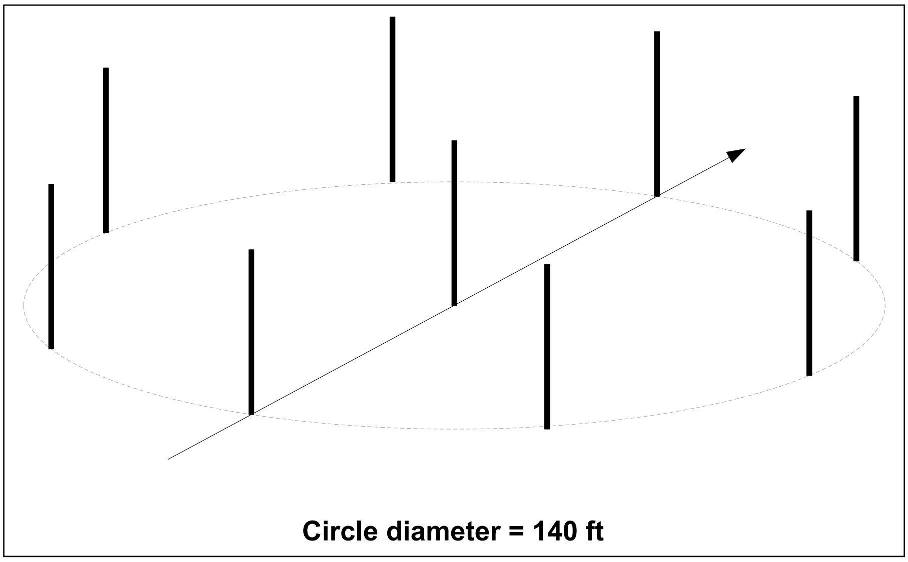

Figure 1 — Nine circle array geometry

Overview

Eight elements are arranged around the perimeter of a circle, and a ninth element is placed at the center. Azimuthal spacing between adjacent elements is 45°. The circle diameter is 140 feet — approximately one quarterwave on 160 meters. There is nothing magic about 140 feet, except that it happens to be the largest dimension that would fit within the space available on my property. Even closer spacings were investigated and found to provide excellent performance as well, but squeezing down the dimensions makes the array more sensitive to amplitude and phasing errors and harder to build as a result. Even 140 feet requires adherence to tight tolerances in order to realize optimal performance.

Although it seems counterintuitive, excellent performance is possible within a small real estate footprint. This is because an in-line configuration of verticals can create a highly directional beam pattern with close spacing between elements. Therefore, a 3 element in-line array was chosen as the basic building block for the 9 circle array. Three in-line elements are active at a time, with the element in center of the circle common to all elements and always active. Switching circuitry selects which pair of in-line elements is used (there is negligible coupling between active and inactive elements). The result is unidirectional end-fire directivity (see Figure 1). You can select any of eight possible coverage directions every 45° in azimuth. I used *EZNEC* modeling software to optimize the amplitude weightings and phase delays of the 3 element in-line configuration (more on this later). The general approach of three active elements at a time can also be applied to simplified versions of this array having six elements on the perimeter of the circle (a 7 circle array) or even five elements (a 5 square array), with fewer switchable directions and somewhat reduced overall cost and complexity.

I chose 15 feet for the height of the individual vertical elements. This height yields good performance on 160 and 80 meters. Greater heights do not improve or otherwise alter the beam pattern but *do* yield somewhat greater signal output. The particular height is not critical, except that all the verticals must be identical.

By design the array's efficiency is very low, which means received signal levels are very low. Inefficiency is of little consequence for a receive-only antenna system, however, because it is easily made up for through RF amplification. In this array a broadband RF preamplifier with a high antenna port input impedance a low output port impedance to match 75 Ω feed lines is installed at the feed point of each of the nine verticals. This arrangement has a number of system advantages. The high input impedance of the preamplifier introduces considerable mismatch loss; at the same time it makes the verticals very insensitive to ground-loss characteristics. For this reason a single ground rod is sufficient for a ground connection. Adding radials offers no benefit in this regard. The preamp's broadband gain also makes it possible for the antenna to function over a relatively wide frequency range. Using this approach it is not necessary — or even desirable — to attempt to tune the vertical elements to resonance.

Some receive-only arrays use short verticals made resonant on a particular

[1]Notes appear on page 18.

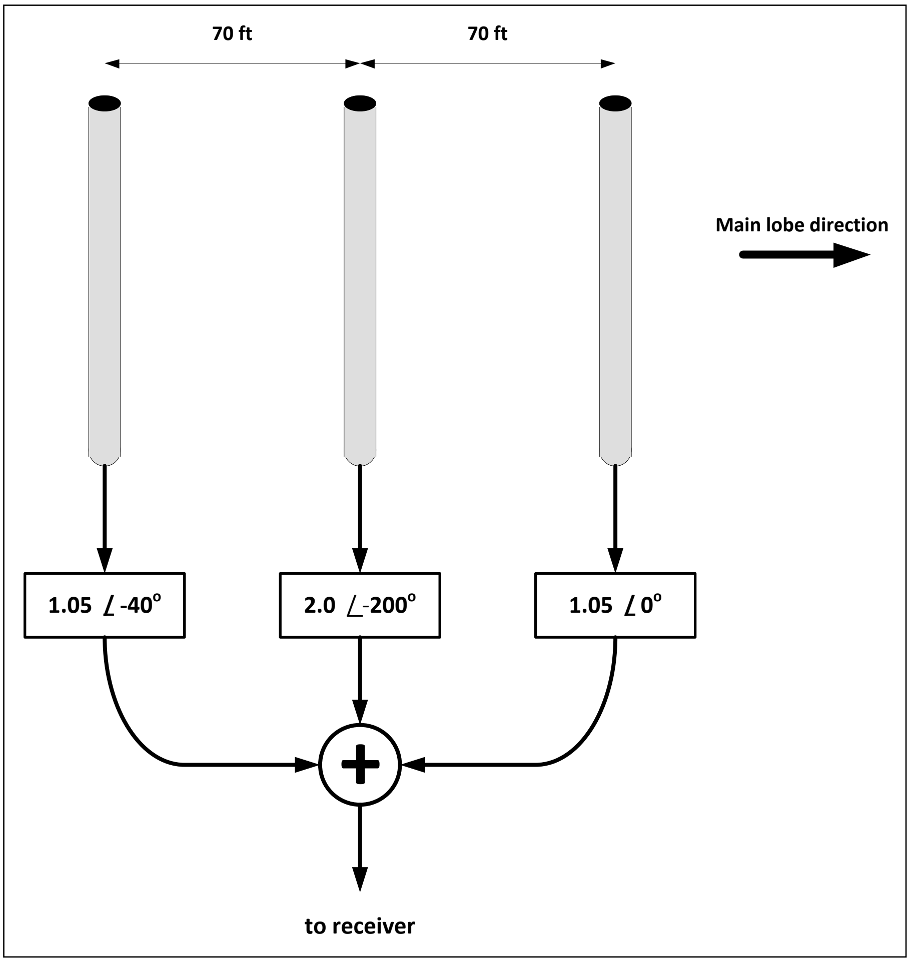

Figure 2 — "Optimized" 3 element inline array for 160 meters

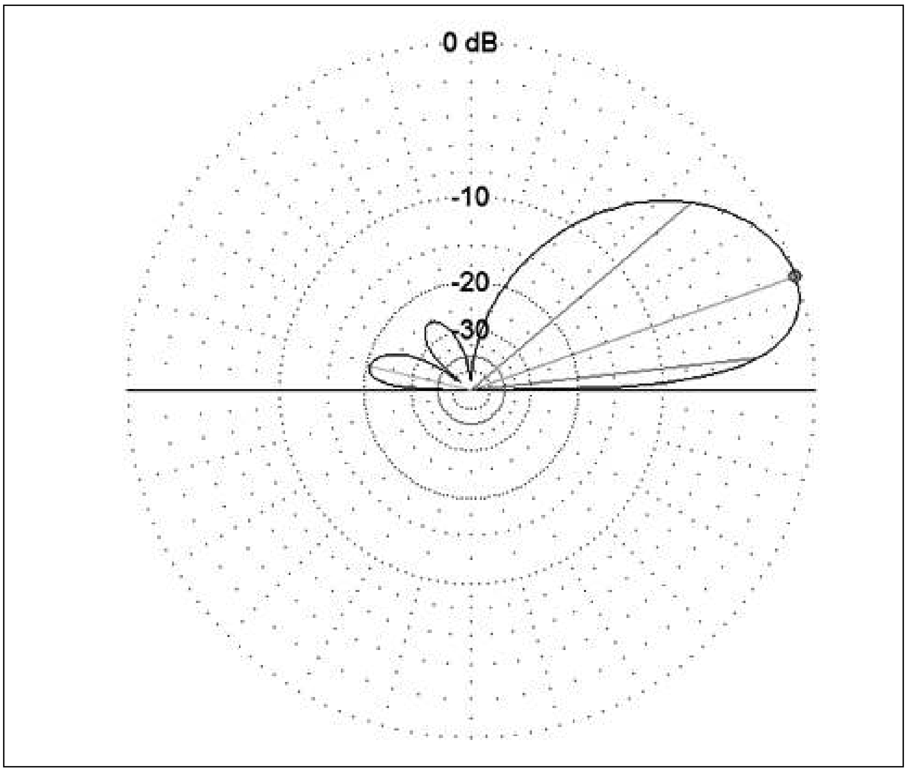

Figure 3 — 160-meter elevation pattern

frequency through the use of base or top loading, and these do not use preamplification at the feed points. On the other hand, these systems usually require radials, and operational bandwidth is relatively narrow. In principle we could employ such an approach with this system, if the user desires only single-band (eg, 160 meter) operation. For the approach described here to work optimally, however, it is critically important that all vertical elements present a 75 Ω resistive load to the feed lines. Equal-length 75 Ω RG-6 feed lines from each element are brought to a combiner/controller circuit that I've located at the array's center. This circuit coherently combines the signals from the verticals with the correct amplitude weightings and phase delays.

The key to broadband operation of the array is to terminate all feed lines in their characteristic impedance, 75 Ω in the case of RG-6. When this condition is met, you can accomplish element phasing with simple delay lines, where the delay angle is equal to the line's electrical length. Delay is independent of frequency, unlike the case where feed lines are not terminated in their characteristic impedance. The combiner/controller circuit used here was designed to provide the required 75 Ω termination on all ports. I'll describe circuit details in Part 2 of this article.

Modeling Results

I used *EZNEC/4* to optimize the signal amplitude weightings and phases for three in-line elements at 70 foot spacing. The objectives were to maximize RDF on 160 meters while restricting side lobe and back lobe levels to no greater than –20 dB with respect to the main lobe at low elevation angles. The ratio of current in the center element to the two end elements is 2:1.05, with relative phases of 0°, –200° and –40°, as shown in Figure 2.

EZNEC's "high accuracy" ground model was employed, assuming "average" ground at a frequency of 1.83 MHz. The ground connection at each vertical was modeled as a four foot ground rod, which *EZNEC/4* allows, because it uses the *NEC-4* engine that can handle buried wires. Several thousand ohms of termination impedance were also added at the feed points of each vertical to model the high-impedance amplifier input. Figure 3 shows the calculated elevation pattern while Figure 4 depicts the azimuth pattern at a 20° takeoff angle.

RDF is probably the single most useful metric to gauge performance of a receiving array in a weak-signal environment where atmospheric noise is the dominant noise source —almost always the case on 160 and 80 meters. On 160 meters *EZNEC/4* calculates the RDF of this array as 12.2 dB at 20° elevation. The RDF of a single quarter-wave vertical is about 5 dB, so the array provides a 7.2 dB RDF advantage over the vertical. In practical terms this means that you can expect the signal-to-noise ratio of low-angle signals to improve by about 7 dB when you switch from the single vertical to the array. This assumes that ambient atmospheric noise is more or less uniformly distributed over all directions. In instances when noise is stronger from certain headings — when there are strong thunderstorms in a particular direction, for example — the signal-to-noise ratio advantage can differ. If the thunderstorms are in the same direction as the desired signal, then the advantage is likely to be smaller, because the array cannot spatially discriminate against the noise source. Conversely when the weather system is to the sides or the rear, the advantage can be greater. Of course, there are also instances where reception is impaired by interfering signals, in which case it is desirable to have a lot of rejection in the direction of the interference. Consequently both high RDF and low side lobe and back lobe levels are desirable properties of an array.

80 Meter Patterns

Because the delay lines provide delay that is independent of frequency, a highly directive beam pattern is also produced on 80 meters with the same combiner/controller circuit used on 160 meters. The actual phase values (in degrees) do, of course, scale directly with frequency when the time delay is constant. As a result, the phases of the three elements (viewed from left to right in Figure 2) become –80°, –220° and 0° respectively (assuming the frequency is doubled from 1.83 to 3.66 MHz)[4], while the amplitude ratios remain the same. Under these conditions the elevation and azimuth beam patterns illustrated in Figures 5 and 6 are obtained.

The RDF on 80 meters is 11.2 dB at 20° elevation, or slightly less than the RDF obtained on 160 meters. Some additional investigation through *EZNEC/4* reveals that the RDF for 80 meters could be improved somewhat to 12.0 dB by relatively small changes to the signal amplitude weightings and phases. To avoid additional complexity in the combiner circuit, however, no provision was made for a separate circuit optimized for 80 meters. The forward lobe beamwidth becomes somewhat narrower as RDF is increased, but the 80 meter side lobe levels also start to increase, so a tradeoff must be made between RDF and side lobes. The array's performance does not extend to 40 meters, because the element spacings become too large in terms of wavelengths to

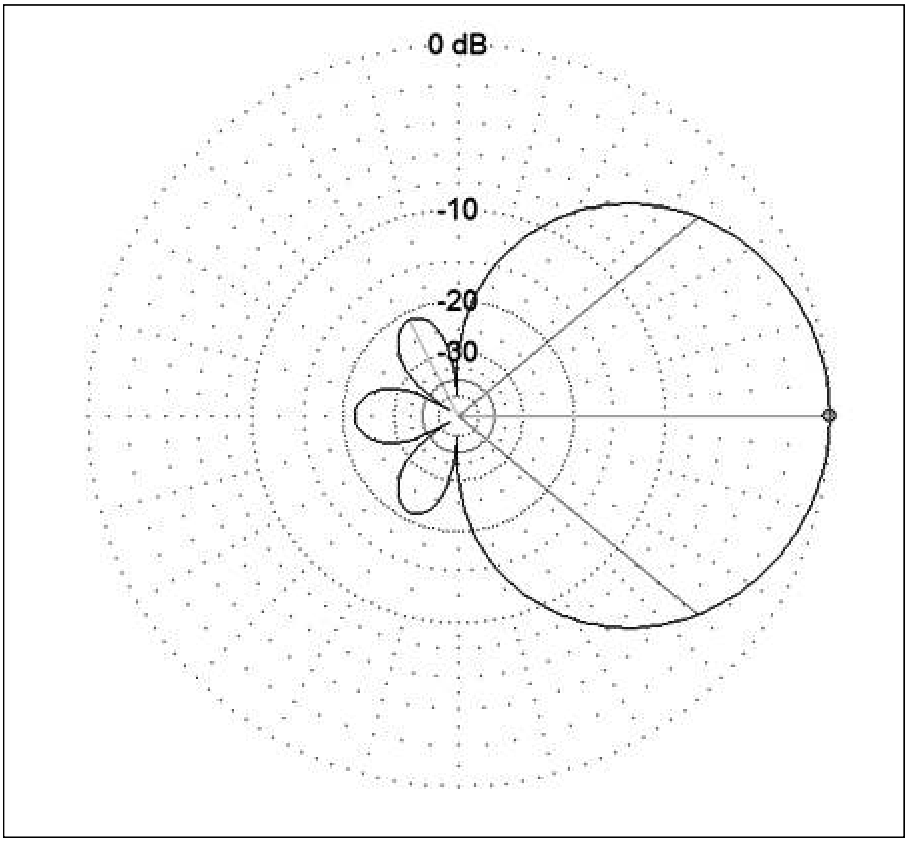

Figure 4 — 160 meter azimuth pattern at a 20° take-off angle.

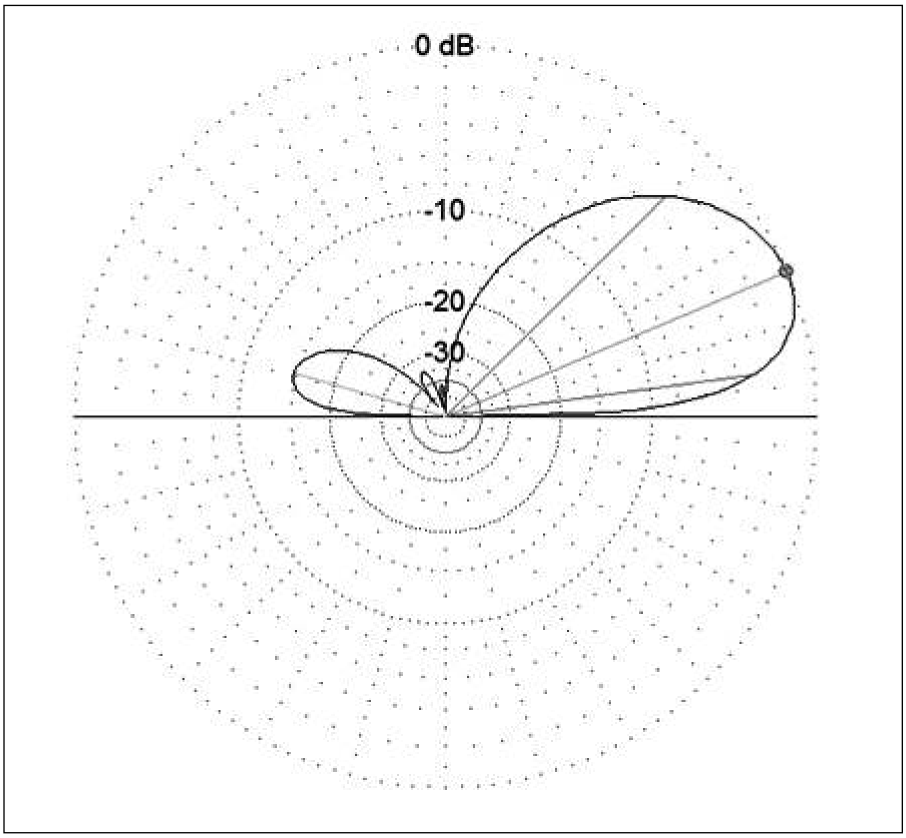

Figure 5 — 80 meter elevation pattern

create a useful beam pattern.

Comparison to Other Receiving Arrays

Suffice to say that this 9 circle array compares favorably in terms of RDF to other high-performance receiving arrays for 160 meters. ON4UN's "Low Band DXing" book describes 8-circle and 9 circle arrays that have RDFs of 12.3 and 12.6 dB respectively.[5] The daunting realization that their required diameters are 320 feet and 415 feet respectively on 160 meters, however, puts a damper on the dreams of many, if not most, of us of ever deploying one of these systems. The compact 9 circle array described here sacrifices almost nothing in RDF to these systems, yet it has a much, much smaller physical footprint. Those larger arrays do have the advantage of greater suppression of signals from sides and rear, however.

The RDF of the compact 9 circle is also about equal to that of an 800 foot terminated Beverage antenna, yet its largest linear dimension is nearly six times less than the Beverage! Although the RDFs of the two antennas are very close, some noteworthy differences in the details of their respective beam patterns are worth exploring.

The 800 foot Beverage has a forward lobe that is about 20 percent narrower in its azimuthal width (at –3 dB) than the 9 circle array, but with an elevation beamwidth that is almost 20% greater (see Figures 7 and 8). The 9 circle's response in the elevation plane is weighted more heavily to low angles.

The Beverage also has much larger secondary lobes at high elevation angles, as is evident in Figure 7. Therefore the 9 circle array and the 800 foot Beverage can be expected to exhibit somewhat different receiving characteristics that are dependent on angle and direction of arrival, even though their RDFs are equivalent.

It should be apparent that a single standalone 3 element in-line array, as described above, can be deployed as a substitute or replacement for a single Beverage antenna when there are space limitations.

In Part 2 of this article (to appear in the November/December issue of *NCJ*), I'll detail on how to build the array, including schematic diagrams for the key circuits and get it working.

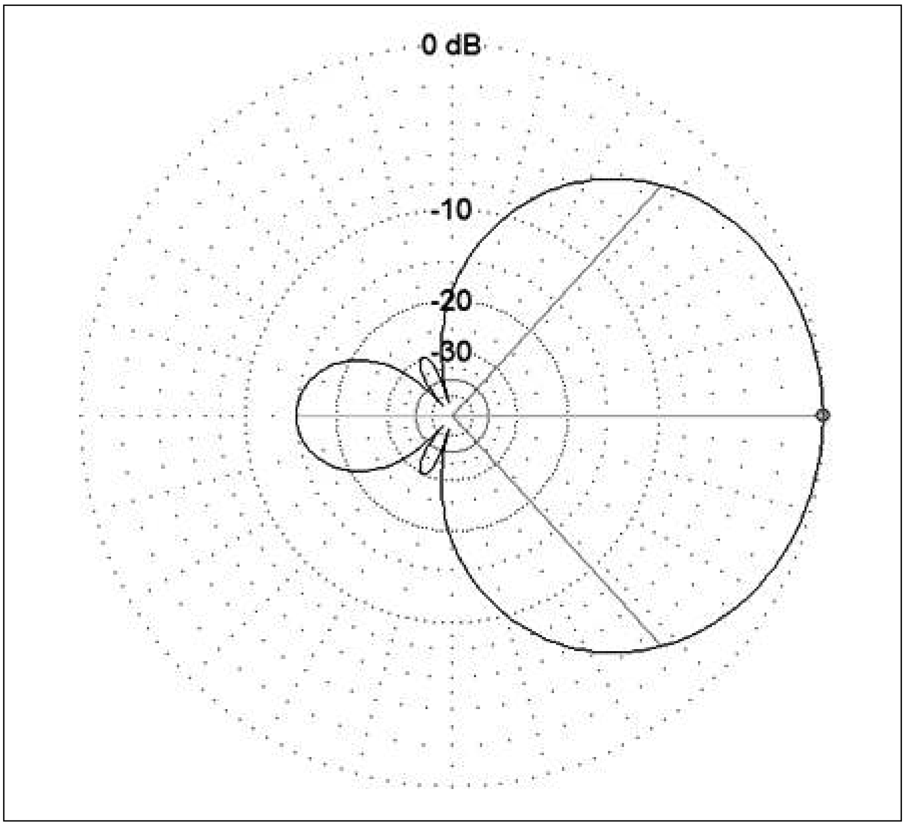

Figure 6 — 80 meter azimuth pattern at a 20° take-off angle.

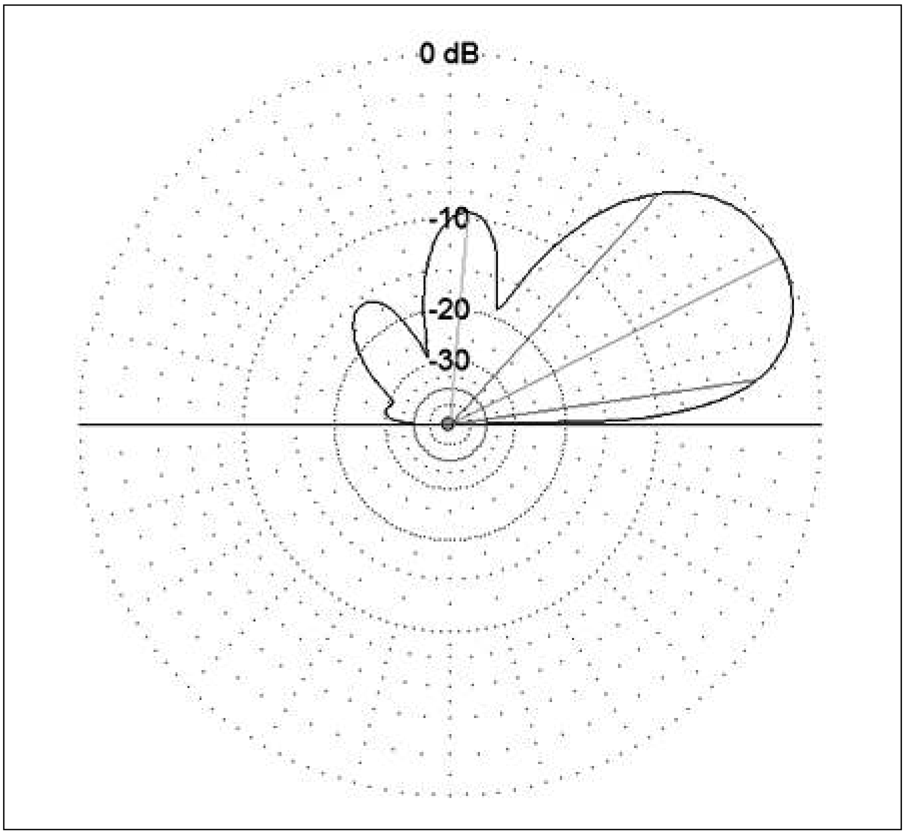

Figure 7 — Elevation pattern of 800 foot Beverage on 160 meters (Note the high-angle secondary lobes.)

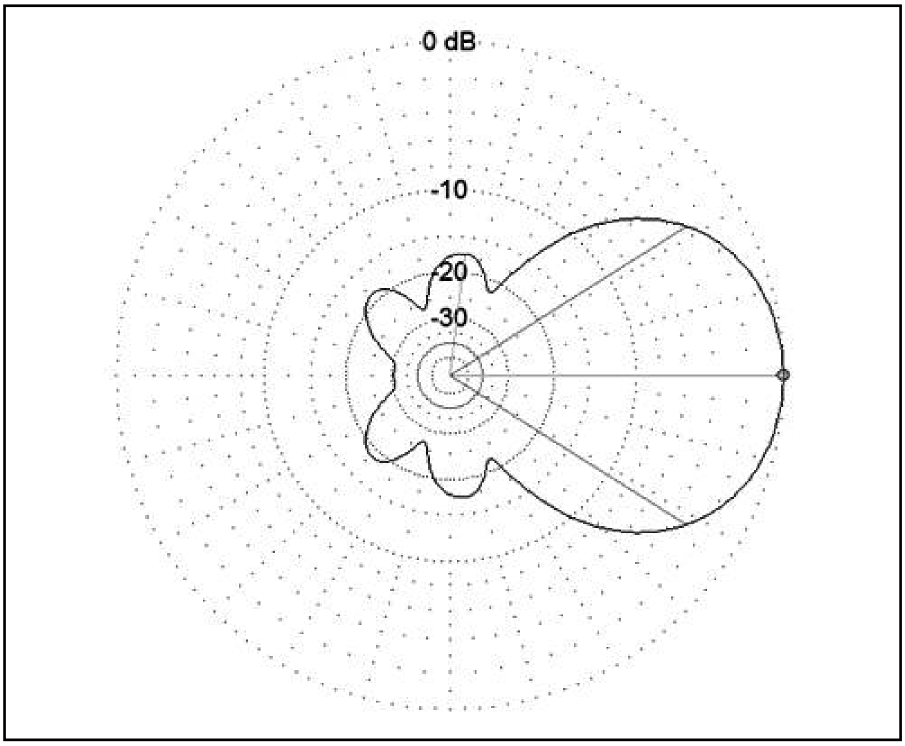

Figure 8 — Azimuth pattern of 800 foot Beverage on 160 meters

Notes

[1]Joel Harrison, W5ZN, and Bob McGwier, N4HY, "Design, Construction and Evaluation of the Eight Circle Vertical Array for Low Band Receiving," *QEX*, Mar/Apr 2010. ARRL

[2]DeVoldere, J., *Low-Band DXing* (5th ed), ch 9. ARRL

[3]DeVoldere, J., *Low-Band DXing* (5th ed), pp 7-10. ARRL

[4]The phasing for the middle vertical includes a 180° phase-reversal element in the beam-forming circuit, so only the phase in excess of 180° scales with frequency in this path. See **www.w8ji.com/crossfire_phasing.htm** for further discussion on the benefits of frequency-independent phase reversal (known as crossfire phasing) for phased arrays. Part 2 of this article will describe details of the phase controller/combiner that I designed.

[5]DeVoldere, J., *Low-Band DXing* (5th ed), ch 7, Table 7-21. ARRL

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